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SEGMENTATION OF
WAR READINESS SPARES KITS

THESIS

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AFIT/GLM/LSM/90S-34

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SEGMENTATION OF WAR READINESS SPARES KITS

THESIS

Presented to the faculty of the School of Logistics

of the Air Force Institute of Technology

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In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Logistics Management

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Preface

The purpose of this study was to develop an algorithm for the segmentation of War Readiness Spares Kits. This algorithm can be used to select the optimal mix of aircraft spare parts subject to an overall volume constraint. A microcomputer based decision support system was developed which implements a selection algorithm based on value per unit of weight for each part considered. Value is computed as the Poisson probability that an additional unit of the item being considered will be required during the specified deployment. Output of this program is a prioritized listing of the kit items considered. I am deeply indebted to a number of people for their assistance in this project. First and foremost, my thesis advisor, Capt John E. Sullivan provided invaluable assistance, helping me set the scope for this project and obtain the data. I also wish to thank Lt Col Phillip E. Miller for his assistance in developing the methodology used and Mr. Jeffrey C. Daneman for his help with the statistical analysis.

<div align="right">Larry A. Martinsen</div>

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Abstract

This study examines the segmentation of war readiness spares kits. Specifically it looks at the possibility of using the volume of available airlift as an additional constraint in the segmentation algorithm. The system currently in use by the Air Force considers only the probability of an item being required.

This paper specifies an algorithm which establishes a quantity of each item for inclusion in the segment. This quantity is directly proportional to the probability of use and inversely proportional to the volume of airlift space which it will require. The probability distribution used is Poisson, with a mean based on historical failures per flying hour. The algorithm is implemented in a dBase III+ program which provides a prioritized listing of parts for inclusion in the kit segment.

The algorithm investigated does not consider indenture relationships or the relative usefulness of the various parts. Only reparable parts were considered. The final section of this study provides recommendations for additional research which could further refine this model.

SEGMENTATION OF WAR READINESS SPARES KITS

I. Introduction

General Issue

War Readiness Spares Kits (WRSK) were established to provide an available stock of aircraft parts for each specific fighter squadron for use during contingencies. Their use has since expanded to include exercises and deployments, and today they are widely used to augment peacetime operating stock. Their reason for existence, and the basis of their composition however, is still the military contingency. Each kit is designed to support its associated fighter squadron in a conflict situation for a period of thirty days (1:14-13). Any two fighter squadrons flying the same mission with the same aircraft are authorized identical WRSK kits. However, when the two squadrons are collocated, the using commands are given the option of storing these kits in a configuration which more closely represents their wartime tasking (1:14-41). Tactical Air Command has used this latitude to establish two different types of WRSK kits to support the two different deployment configurations of fighter squadrons: dependent and independent. An independent fighter squadron deployment takes with it everything it will need to sustain itself in combat, including intermediate level maintenance which has

the capability of repairing many aircraft components in the field. The independent WRSK then, must include the shop replaceable components of the line replaceable units (LRUs) which the intermediate level maintenance will require, as well as components to repair the maintenance equipment. The dependent WRSK, on the other hand, relies on the intermediate maintenance capability of a similiar unit, deployed to the same location and may therefore be somewhat smaller.

In response to the need for a system to manage the world wide logistics support effort and predict the sustainability of combat forces, the Air Force has established the Weapon System Management Information System (WSMIS) (2,2-1), a combat logistics command and control system. The portion of this system which computes aircraft spare parts requirements and estimates the level of combat performance which these parts can support is the Requirements/Execution Availability Logistics Module (REALM) (2:2-11). REALM uses the Dyna-METRIC model to establish the relationship between stock levels and aircraft availability for any specified level of employment activity (2:2-1).

Dyna-METRIC, through REALM, is now being used to compute the optimal mix of parts for WRSK kits. A microcomputer based system, using a more limited version of the same model, developed for use at base level, is the Dyna-METRIC Microcomputer Analysis System (DMAS) (3).

Since demand for parts is probabalistic, any system which attempts to ensure that all demands are met will result in an infinitely large WRSK (4:4-15). To overcome this problem, DMAS (and Dyna-METRIC itself) uses the cost of each item to compute the best mix of parts subject to a total dollar value which represents the amount of money which the program's user is willing to invest in the kit. For deployment computations, DMAS has an option which permits the user to set the dollar value of all components to zero so that the only basis for inclusion in a WRSK segment to support the deployment is the probability of the item being needed during deployed operations. This system does not however, consider the size of the individual components or the amount of airlift available. Reske and McGlish noted this shortcoming in a recent article and recommended replacing the cost data in DMAS with volumetric data for deployment computations (5). In the 1950s, RAND Corporation, working on flyaway kits for the B-47 and F-100, recommended dividing anticipated demand by weight to optimize the kits then in use. An algorithm of this nature would permit optimal tailoring of a kit to meet an overall airlift constraint, and would enable WRSK managers to provide optimal support throughout a time-phased deployment.

Deployment of a large fighter wing can take up to a week of continuous airlift. Even assuming the national command authorities will be able to dedicate this much airlift to the wing, the fighter aircraft will arrive at the

5. What is the best algorithm for allocating parts to the kit based on the desire to minimize unfilled demands, subject to a given size constraint?

6. If an algorithm can be developed, what is the best way to make it available for general use?

Scope

The intent of this thesis was to develop an algorithm which would suggest composition of a size constrained WRSK segment.

The focus of this study was on reparable items used on aircraft. Expendable items are generally small in size and not individually packaged. For these reasons, they were not treated individually. The implementation presented in this paper permits the user to reserve an arbitrary amount of pallet space for bench stock.

Shop replaceable components of LRUs were not included. Segmentation of WRSK serves two purposes. It provides support to a deployment of less than a full squadron and it optimizes support during a time phased deployment. In the first case, deployment of less than a full squadron, intermediate level repair capability is not normally included in the maintenance support package, and in the second case, the time phased deployment, intermediate repair capability is sent, but is not normally operational until the completion of the deployment. That is, the intermediate level diagnostic test and repair equipment cannot be

expected to become operational at the deployed site until

after all, or nearly all, of the WRSK pallets have arrived.

Though the algorithm assigns parts to specific pallets

as closely as possible, no attempt is made to dictate

specific placement on the pallet. Items should be

palletized in accordance with Air Force Regulation (AFR)

28-4 (6), AFR 71-4 (7) and Military Airlift Command aircraft

specific technical orders.

II. Background and Review of Literature

Overview

Aircraft components, like all complex equipment items are subject to failure. Aircraft availability then, depends, to a large extent, on having the right mix of spare parts available when and where they are needed. Because of the high cost of purchasing, transporting and warehousing these parts, it is essential to optimize the number of each to be stocked. Accurate prediction of failure rates and hence stockage objectives, has proven to be extremely elusive (8). In an effort to better predict parts requirements, the Air Force contracted the RAND Corporation to investigate various techniques for predicting demand and to determine efficient stockage algorithms. Over the last thirty years, RAND has done a great deal of work in this area, publishing over thirty related reports.

The RAND reports which are most closely related to the goal of this study are those detailing the work done with F-100 and B-47 flyaway kits (9). The approach used in these efforts was to rank each successive unit of each item by the protection against stockout it would provide per pound, multiplied by a factor representing the subjective assessment of that item's essentiality. Protection against stockout was computed using the anticipated mean demand and a Poisson distribution. The essentiality factor was a

number between zero and one assigned to each item subjectively by a group of maintenance experts. They found that the Poisson distribution worked fairly well, but both applications had problems in two areas. The first was the lack of an established computerized database for parts and consumption data. They found an unacceptably high percentage of demands were for items not listed in their master parts listings. The second problem area was in the demand for consumables. They found technicians were prone to round up their requested quantities for small items so that requests for 5 or 10 each were extremely common. They also found the computer established stockage levels of shop stock type items were often less than the smallest useable increment. In their example, "the first inch of tubing may be of no use whatsoever unless it is accompanied by the next hundred inches" (9:45). A related issue is trying to determine how much protection against stockout is provided by 100 inches of hose (or other shop stock type item), when useable lengths are, for example, 20, 30, and 90 inches. In spite of these difficulties, the computer generated kits provided significantly better protection against stockouts than the subjectively established kits then in use.

Current Models

The most widely used spare parts stockage computation system currently available is RAND Corporation's Dyna-METRIC, developed in 1982 and revised four times since then

(10:1). Dyna-METRIC is a highly complex model with a basic

structure as outlined in the diagram in figure 1 (11:4).
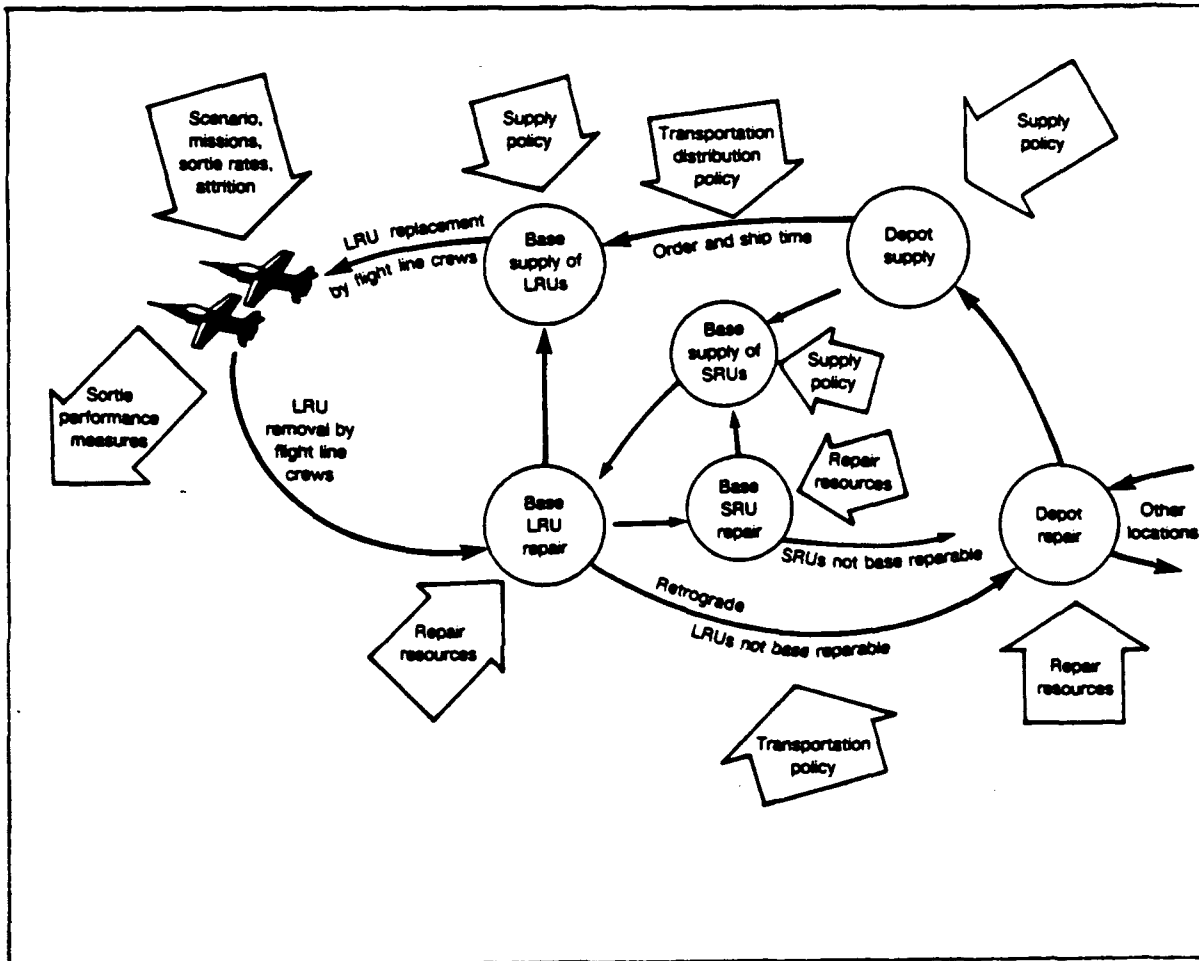
Figure 1. Dyna-METRIC Model (11:6)

This model is primarily used for weapon system management by

the program managers and major commands where a macro view

of a weapon system is required. It is used extensively to

determine U.S. warfighting capability and to evaluate the

impact on that capability of spares acquisition/stockage

decisions (12:1). Tailoring this model for the purposes of

this study would eliminate all but the "Sortie" and "Base Supply of LRUs" nodes on the left hand side.

A somewhat tailored version of this model is the Dyna-METRIC Microcomputer Analysis System (DMAS) (3), designed by Dynamics Research Corporation for the WSMIS program office and distributed by Air Force Logistics Command (AFLC/LMSC/SMWW). In order to fit the model into a microcomputer, the "view" or system being modeled is restricted to a single base, though resupply from a variety of sources is still considered. Both DMAS and the full Dyna-METRIC are primarily concerned with finding the least cost mix of parts given a required level of support (11:62) and are used extensively to evaluate warplanning and in determining WRSK requirements. However, when a WRSK is segmented for deployment, all parts are already bought. That is, since the entire WRSK was purchased in the past, cost of the parts to be included in a deploying segment of WRSK should not be considered (13). Instead the needed algorithm would maximize the level of support given a physical size constraint, the airlift available.

Predicting Component Failures

Both DMAS and most versions of Dyna-METRIC use a Poisson distribution to predict failures. A general consensus in the literature suggests theoretically, at least, the Poisson distribution should adequately predict the number of failures for aircraft components over time

(11:7-8; 14:51-52; 15:3). However, many authors are concerned about the widely varying variance-to-mean ratios observed in the empirical data (5; 14:58-59; 15:3-7; 16). Those voicing this concern seem to be evenly split between those who feel the modeling distribution should be changed (14; 16; 17) and those who feel the inputs to the model should be modified to more accurately account for the factors impacting component failure (14; 15).

Establishing the Demand Distribution

Assume the occurrence of demand is completely random. This implies the lengths of the intervals between demands are independent and identically distributed. Wagner, in his text, demonstrates a method for establishing the density of these random occurrences (18: 842-845).

Let λ equal the mean demand rate per unit time. Then $1/\lambda$ equals the mean time between demands. And the probability the first demand occurs after time T becomes:

$$P(t \geq T) := e^{-\lambda \cdot T} \qquad (1)$$

So the probability density function, f(t), becomes:

$$f(t) := \lambda \cdot e^{-\lambda \cdot t} \qquad (2)$$

As can be seen in the graph in figure 2, this is an exponential distribution. Now the probability of n demands occurring in any time interval, (O,T), becomes:

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$$Pn(T) := \frac{(\lambda \cdot T)^n \cdot e^{-\lambda \cdot T}}{n!} \qquad (3)$$

Which is the Poisson distribution shown in figure 3.

Note: If the assumption that demand is completely random is accepted, then the interarrival times for failures must be exponential and the cumulative demand distribution must be Poisson.
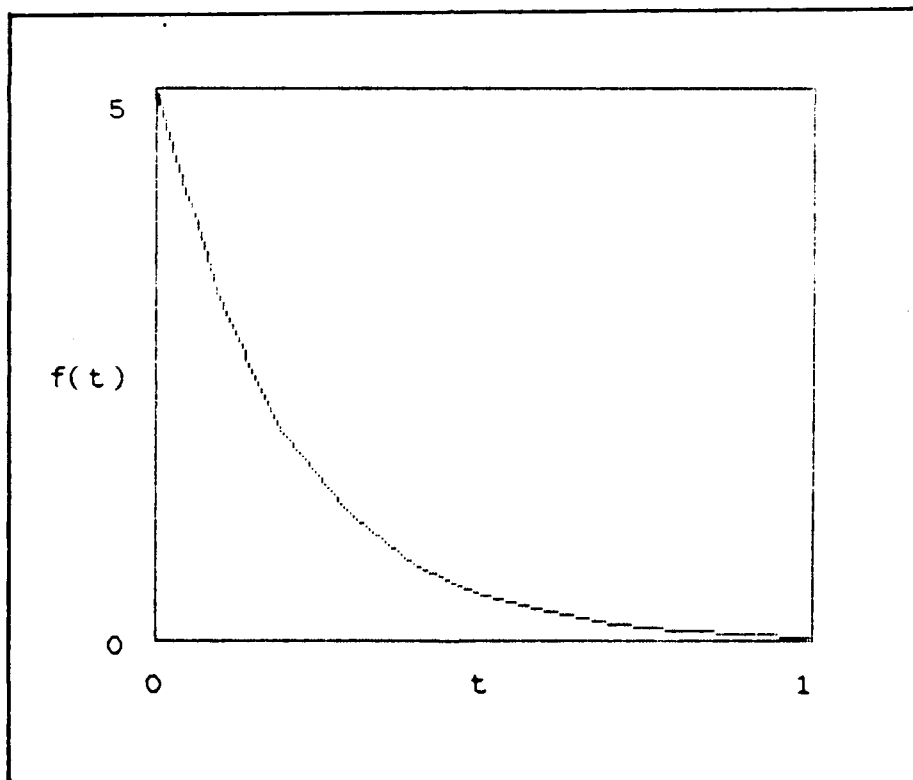
Figure 2. Exponential Distribution
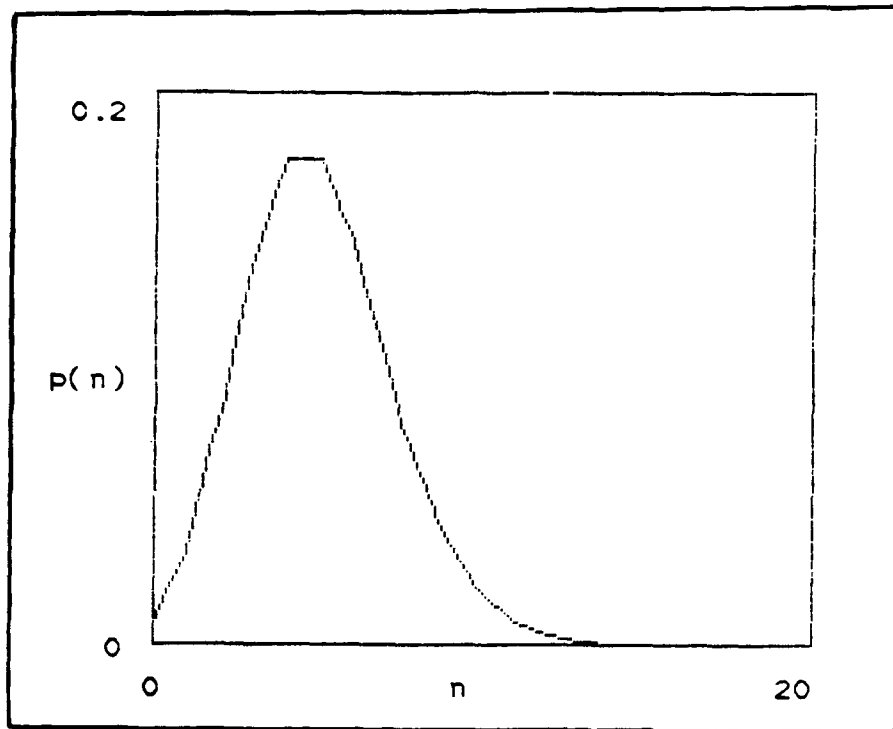
Figure 3. Poisson Distribution

Analysis of the Poisson Assumptions

Because applicability of the Poisson distribution depends on an exponential interarrival time of failures, the following preconditions of the exponential distribution apply (14:17-29).

Independence of Individual Failures. This condition is met if one failure does not cause another failure. It is generally considered to be met for aircraft mission critical systems since special engineering care is taken to prevent

cascading failures which could result in catastrophic degeneration and loss of the aircraft during flight (15). A more subtle application of this condition considers the possibility of additional stress placed on one component by failure of another. This increased stress, if repeated a number of times, may hasten the failure of the stressed component without causing immediate failure, but significantly shortening its lifespan. However, if such stresses occur frequently enough relative to the expected life of the part, they could be considered normal usage and thus would not preclude application of the Poisson distribution. A final consideration in this category is that a failure in one aircraft may cause a one time inspection of the entire fleet for similiar defects. This would result in failures which had built up over a period of time being felt as a cluster of demands. Such occurrences are often to blame for higher than expected variance-to-mean ratios (15).

Identical Distribution of Failures. This condition is met if all parts of a given type have the same probability of failure. A large body of evidence suggests most complex components experience a bathtub distribution of failures (see figure 4) (15:26-28).

Applying this distribution, components fail at a relatively high rate when new, representing a burn-in process which weeds out poorly manufactured items, and then

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proceed through life at a relatively constant and low
failure rate until they reach the end of their useful life,
at which time the failure rate again increases. Aircraft
spare parts, however, do not necessarily fit this model
since the vast majority of "new" aircraft parts are parts
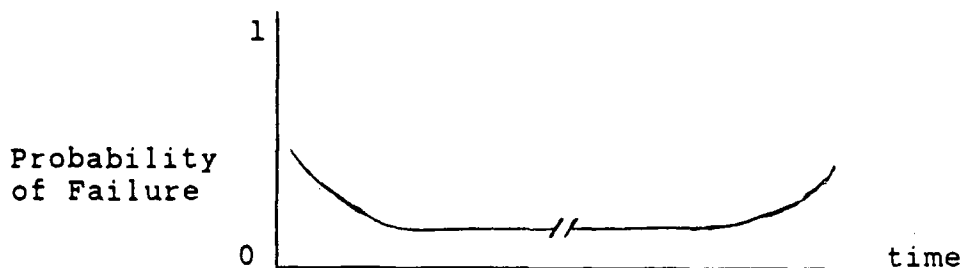
Figure 4   Typical Bathtub Distribution

which have themselves failed previously and been repaired.
At the other end of the spectrum, the Air Force requires
contractors to test a percentage of each critical component
to failure in order to determine the point at which an
increased failure rate occurs. When such a point is
determined, the service issues directives ordering
preventive replacement of these parts before any increase in
failure rate can occur in the general population. The Air
Force sets acceptable levels of reliability. Military
Specification Mil-F-9490: Flight Control Systems - Design,
Installation and Test of Piloted Aircraft, General
Specification (19) requires, among other things:

> If the probability of control system failure is
> greater than 10^{-5} per flight hour, then the
> aircraft structure should be designed assuming
> the system to be inoperative at all times.
> (20:11)

There are, however, still cases of bad batches after an

aircraft modification program which have been found to

impact variance-to-mean ratios.

A Steady State System. This condition is met if the

system is neither improving nor decaying. An operational

aircraft system is normally at steady state, although from

time to time, it may be improved through a modification

which increases its reliability or conversely may decay,

either through a poorly engineered modification or through

deterioration as the system reaches the end of its life

span. While situations occasionally arise which temporarily

invalidate this assumption, if this requirement is reviewed

before application of the model, it should not disqualify

the model for most situations.

Nonrenewal. This condition stipulates that repair

should return the system to the state that existed before

failure. In other words, the component which replaces the

failed component should have the same probability of failure

as the item it replaces. Since a large majority of aircraft

replacement parts are repair cycle assets which have failed

and been repaired one or more times, this condition should

generally be satisfied.

Model Inputs

There are two categories of inputs to any requirements model: equations and data. Equations are the mathematical representation of the model and data represents the values that can be assumed by the variables in the model. Both inputs require careful evaluation since both affect the variance-to-mean values.

Input Equations. The equation of most concern is the one used to compute daily demand rates. For the Dyna-METRIC model, that equation is (11):

$$ddr = \frac{failures}{flying\ hr} * \frac{flying\ hrs}{day} * \frac{\#\ aircraft}{1} * \frac{\#\ components}{aircraft}$$

$$(5)$$

The assumption Dyna-METRIC makes here is flying hours are, by themselves, a sufficient predictor of component failures. Many other possible contributing factors have been suggested for consideration including on-off cycles (14:66), weather (14:66), and even performance of maintenance itself (14:67; 16:45).

DeGroot, in his 1988 thesis (16), evaluated the Dyna-METRIC model's performance against an actual Air Force exercise. He attributed a significant portion of the substantial error he encountered to the model's linearity. He concluded that in the flying scenario he had chosen, sorties or sortie attempts were important factors which the model ignored. Because of this limitation, he felt the

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model was inadequate for use in segmentation of the kit. There are many obvious examples of failures which are more related to on-off cycling than to flying hours. One is failure of tires or landing gear components. These items are only used during takeoff and landing, regardless of how long the flight is. A second example is the frequent occurrence of component failure prior to takeoff. Component failure of this nature is generally attributed to the changing voltages, temperatures, and pressures associated with system start up. The effects of on-off cycling may be negligible when average sortie duration remains constant, since the failures associated with each launch and landing are spread over the same number of flight hours. This does not necessarily hold for mission specific components like the gun system, which may experience heavy use at infrequent intervals.

Temperature differentials between ambient and normal operating temperature are magnified by the extremes in climate under which aircraft are required to operate. Aircraft systems acclimated to a hot climate which are taken to a cold climate to operate experience frequent failures of their hydraulic and pneumatic components, whereas systems acclimated to a cold climate which are taken to a hot climate to operate experience frequent failures of their air conditioning and avionics components (15).

Blanchard asserts that the act of performing maintenance on a system will reduce the reliability of that

system (17). He bases this assertion on the inevitable wear caused by component removal and installation as well as the possibility of the technician inadvertently injecting a fault into the system either through carelessness or ignorance.

Input Data. Crawford (15) looked at the historical data on which the Dyna-METRIC model relies to establish daily demand rates in an effort to trim outliers and predict clustering of data. He used a database consisting of 19 F-15 parts and went to two different bases which have F-15s, talking to maintenance personnel in an attempt to find explanations for the differences in variance-to-mean ratios seen in the data. His work produced the following conclusions:

1. Removals occur in clusters. Driving factors for this included weather, mission requirements, and asset availability.

2. Certain flying scenarios place a premium on the proper operation of particular systems. He found, in anticipation of these requirements, it was common to perform rigorous evaluation of these systems and replace marginal components.

3. He also found that when supply of certain components was not available, the parts were not removed, even though removal was indicated by maintenance testing.

This resulted in pent up demand which manifested itself as a cluster of demands as soon as assets became available.

It is important to note that all of these conditions, while they may appear random from the perspective of an item manager, are largely predictable at the base level. This means they can be factored out during base level requirements computations.

Space Allocation Algorithms

An essential part of this thesis is the selection of an algorithm to allocate the available pallet space in a way to minimize the probability of a needed part not being included in the WRSK segment. Algorithms for the efficient allocation of limited space represent an important branch of operations research. They are used for everything from determining which systems should be made redundant on a spacecraft to allocating computer disk space (21). The basic problem type is the integer linear programming problem (22:340-341). In linear programming, the constraint equations are solved simultaneously for the optimal solution. The constraint equations in this case would represent the size of each individual part in comparison to the total available space, while the objective function would represent the protection against stockout provided by the selected number of each item (22:345-346).

General linear programming solutions are fairly straight forward. However, when the solution space is confined to integer values, as in this case, the complexity

is greatly increased and heuristic solutions become necessary (22:234,343).

Theory. The particular class of integer programming problems represented by the palletization of WRSK is known as the knapsack problem. The goal, in a knapsack problem, is to choose from among a set of items, the subset which will maximize the value of that subset, subject to a capacity constraint. Cook and Russell (22:344-348) recommend a branch-and-bound algorithm which works in a 'greedy' method, successively adding to the knapsack the item which has the greatest value-to-weight ratio. This is done until the last item selected will not fit in the knapsack. Since this item would have been the best selection, had it fit, the value of the contents of the knapsack, with this item included, becomes the upper bound on the value of the solution, and the value without this item, becomes the lower bound. The solution set then branches, with one branch including this item and attempting to obtain an improved feasible solution by discarding one or more previously selected items while the other branch discards the last item and attempts to fill the remaining space with other items. Each feasible solution found is compared to the lower bound and when an improved feasible solution is found, it becomes the new lower bound. Branches are followed until they cease to generate improved solutions.

Practical Implementations. Karr, Geisler and Brown (9), in their work for the RAND Corporation, used a marginal protection scheme which implemented the greedy portion of the above algorithm, but left the final portion of space unallocated. They concluded that the small space remaining, when the next item in their prioritized list would not fit, was insignificant in terms of the amount of improvement which could be expected by implementing a more detailed algorithm. Their marginal protection scheme divided the probability of needing an item (assuming exponential demands and an empirically obtained demand rate) by the weight of the item to obtain a "marginal protection per pound" (9:21).

They evaluated their work against actual fighter squadrons in Europe and the United States, finding that a linear increase in the allowable weight of the kit resulted in an exponentially decaying marginal improvement in protection against stockouts as illustrated in figure 5 (9:50).

Nordin and Maier more recently used a very similiar algorithm in their SPAREL computer modelling program which evaluates system reliability considering availability, redundancy and logistics support (23). The program can be used to determine the optimal mix of LRUs to maximize system availability given a financial investment constraint. Again, the algorithm is a 'greedy' one which iteratively selects the LRU providing the greatest increase in system availability in relation to its price. Again, the Poisson

distribution is used to determine the probability of a given number of failures.
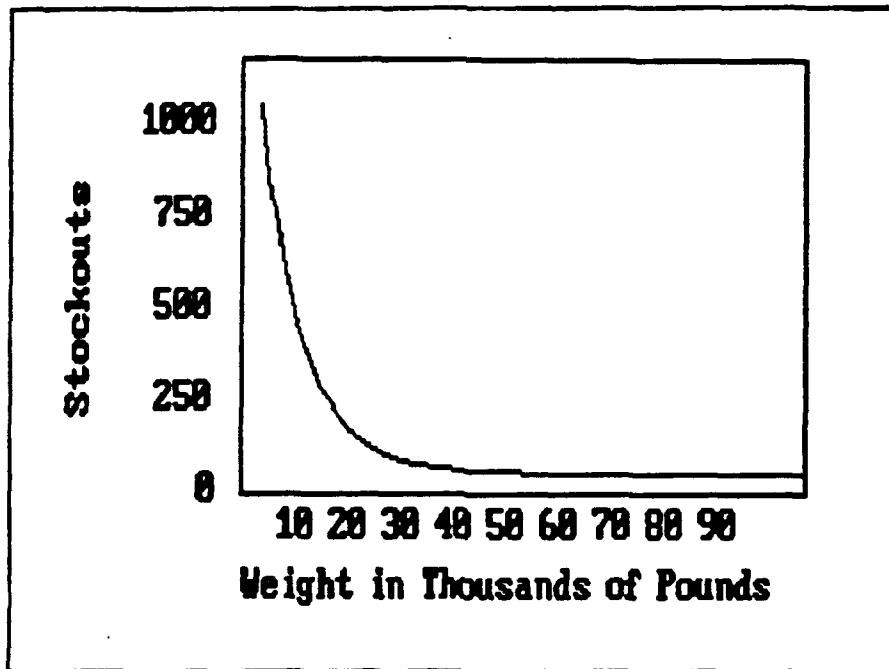
Figure 5. Effect of the Weight Limit on Flyaway Kit
Performance (9:50)

Conclusions

1. Flying hours are a reliable predictor of demand for any aircraft components in continuous use throughout flight. They are also reliable predictors for components which are in use for a relatively constant percentage of flight time, e.g. landing gear components. They should not, however, be used for components which are only infrequently or intermittently used, unless use in the period being forcast mirrors average use statistics.

2. Although there is some empirical evidence against it, the Poisson distribution would seem to be the best model of demand requirements. Discrepancies observed in application of the Poisson can most likely be explained by proper analysis of the inputs, which must include both historical demand data and inputs to the average daily demand rate computations.

3. The best algorithm for allocating parts to a WRSK segment is a marginal improvement algorithm which iteratively selects the part with the highest benefit/cost ratio. Benefit is calculated in terms of the reduction in probability of an unmet demand which inclusion of a specific item would provide. Cost is calculated in terms of the airlift capability consumed by the specific part, either its volume or weight, whichever turns out to be the dominant constraint.

III. METHODOLOGY

Overall Approach

Items compete for a place in the WRSK segment based on two factors: size and utility. Larger items are penalized because it may be possible to replace them with a number of smaller items whose cumulative utility is larger. The goal is to obtain the largest total utility for the kit.

Evaluation of Utility

Utility for any single item is based on two factors: demand rate and demand distribution. If demands were completely deterministic it would be possible to base the quantity on demand rate alone. However since demands are probabalistic it is necessary to use the demand rate as the mean for the probability distribution for demand. In the diagram in figure 6, the X axis represents the number of
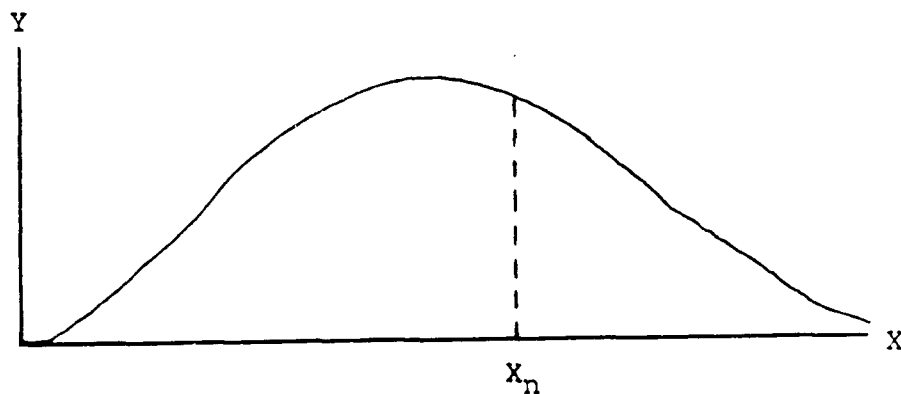
Figure 6. Typical Probability Distribution

demands, the Y axis represents the probability of occurrence and the area under the curve to the right of any point X_n represents the cumulative probability of X_n or more demands. Utility of the nth occurrence of a particular stock numbered item then is represented by the area under the curve from X_{n-1} to X_n.

Since the selected interarrival function for component demands is exponential, the cumulative probability function is Poisson as previously explained. Calculation of the Poisson distribution requires the use of both natural logarithms and factorials. These calculations must be performed for every part in the WRSK to obtain an initial priority listing, and then as each part is added to the segment, that part's priority must be recalculated. These calculations would be extremely time consuming if performed by hand, but are relatively trivial for a computer. For this reason, a computer program was written to perform the calculations necessary to segment WRSK kits (See Appendix B). An MS-DOS computer was used as the host system for this program because of its ready availability. dBase 3 Plus was chosen as the host language because of its record handling capability, and because of its widespread use throughout the Air Force.

Size as a Constraint

Size may form a constraint in one of two ways, weight or volume. In the RAND studies mentioned earlier in this

research, weight was used as the dominant constraint (9). Since that time however, the design of aircraft has changed to the point where that probably no longer holds. Today's more powerful aircraft are quite likely, more constrained by volume than by weight. To verify this, pallet weight and dimensional capacities were obtained for the C-130, C-141, and C-5 aircraft. The majority of pallet positions in all three aircraft are restricted to dimensions of 88x108x96 inches, for a total of 912,384 cubic inches and a weight per pallet of 10,354 pounds (24). A statistical analysis was performed on the 164 individual line items in the F-16 WRSK in hopes of drawing firm conclusions of the dominance of one constraint or the other. However, this proved inconclusive. Next, an optimal kit was drawn up for a hypothetical TDY, unconstrained by authorized levels. Weight and volume of each pallet in this kit was evaluated. Finally, the 164 parts were ranked by density, and a pallet listing was generated starting with the most dense part and proceeding through the list. The full authorized quantity of each part was added to the pallet, until the pallet was full. The weight of this pallet was then compared to the maximum allowable weight of 10,354 pounds.

After the parts have been prioritized for inclusion in the kit segment, a cutoff point must be established to determine which parts will go into the segment. Since the purpose of this project was to determine the optimum mix of parts for a given airlift constraint, total volume available

is a given. Volumetric data for each part is available from Air Force Logistics Command. However, simple subtraction of the volume of each part from the total volume available would overstate the number of parts that can be included. Since each part has a unique size and shape, there will be some loss of efficiency in combining them into pallets. Total available space is equal to the pallet load dimensions (length, width and height restriction) multiplied together minus mean wasted space times the number of pallet positions available. Total space per pallet is 912,384 cubic inches, from which must be subtracted the mean wasted space to get available space per pallet. That, multiplied by the number of pallet posi'' ns allocated to WRSK, gives total available space.

The foregoing assumes volume is the more restrictive constraint. The alternative would have weight as the primary constraint. Had analysis determined weight to be the dominant constraint the problem would have been simplified since there is no loss of efficiency in combining different weights.

It is possible, though unlikely, for some WRSK kits, neither constraint is dominant in all cases. Should this occur, it would be necessary to include both constraints in the algorithm.

The F-16 was selected as the object weapon system for this study because it is the most prevalent tactical system

in current use. Also, data was readily available from F-16 units stationed at both Shaw and Wright-Patterson AFB.

An attempt was made to evaluate a palletized WRSK database from Shaw AFB to determine the mean and standard deviation of wasted space per pallet. Wasted space for each pallet was to be calculated as the difference between the total space available (912,384 inches) and the sum of the volumes of the items presently loaded on the pallets. However, this proved impossible because each of the pallets contained a large number of EOQ items. Using computations based on packaged sizes of individual EOQ items is not realistic since these items are not packaged individually. If all EOQ items on each pallet could have been identified to specific bins or boxes and if the dimensions of these larger containers had been available, it would have been possible to perform the calculations by including the EOQ containers with the reparables. Unfortunately, this information was unavailable.

Data Sources

The F-16 WRSK listing used for this study was obtained from the Weapon System Management System (WSMIS) program office. Dimensional data for the majority of the reparable parts was obtained from Headquarters, Air Force Logistics Command/XPSA. Information on the remainder of the items was obtained from the F-16 System Program Office and from the WRSK section of the 906th Tactical Fighter Group, Air Force Reserve at Wright-Patterson AFB.

The accuracy of the AFLC database was called into
question by this research, when the dimensions given by it
for several of the items did not agree with actual
measurements of parts from the 906th kit. Discrepancies,
when they occurred, were typically an inch or two in one or
two dimensions. The AFLC database is several years old, and
it is likely discrepancies are due to recent modifications
to either the parts or the packaging. It was decided the
information available was sufficiently accurate for the
purposes of demonstrating the concepts presented in this
study, but inaccuracies may result if this data is used for
planning actual deployments.

Demand Rate Computations

Demand rates in the WSMIS database are expressed in
demands per flying hour, so mean anticipated demands (MAD)
for any part can be calculated using equation 6.

$$\text{MAD} = \text{Daily Demand Rate} * \# \text{Aircraft} * \text{Sortie Duration} * \# \text{Days} * \text{Sorties per Aircraft per Day} \tag{6}$$

Then, the probability of exactly n demands, assuming the
Poisson distribution is:

$$\text{Prob}(n) = (\text{MAD}^n * e^{-\text{MAD}}) / n! \tag{7}$$

The Allocation Algorithm

The allocation algorithm itself is a greedy algorithm
selecting the part giving the greatest marginal improvement

in protection against stockout per unit volume. A table is established listing the parts in column one, the probability of one or more demands in column two, the volume of each part in column 3 and the marginal protection (column two divided by column 3) in column 4. The part with the largest value in column 4 is selected for inclusion in the kit. The corresponding value in column 2 is then updated to reflect the probability of the next unit being needed, i.e. the probability of two or more demands. This procedure is repeated until the total volume of the selected parts is greater than or equal to the available space. Since available volume is only an estimate and prioritized lists of recommendations for additions or deletions are available, the algorithm will terminate at this point.

The following example should clarify the procedure. Assume a kit consisting of three parts: A, B, and C. Each has a unique number of mean anticipated demands during a proposed deployment and each has a unique size. The initial priority for each part is computed by dividing the probability that one or more of that part will be required by its size. Table 1 lists the three parts in the leftmost column. The second column gives the mean anticipated demands for the deployment which is obtained by multiplying the historical demands per flying hour times the projected total number of flying hours for the deployment. The probability of one or more demands is calculated by subtracting from one, the Poisson probability of zero

demands, for a distribution with the mean from column two.
Finally, priority is calculated by dividing the probability
of use by the item's size.

TABLE 1

PARTS PRIORITIZATION - INITIAL PASS

	mean anticpated demands	probability of one or more demands	size in cubic inches	priority
A	1	.632	20	.03160
B	3	.950	40	.02375
C	2	.865	50	.01730

In this example, part A has the highest priority, so it is
selected for inclusion in the kit. Note that it did not
have the highest probability of use, but rather, it provided
the best use of the space which it will occupy. To continue
the selection process, we now compute the probability of two
or more demands for part A and the associated priority,
comparing that to one or more demands for each of the other
parts. Only the probability for part A had to be calculated
because we are evaluating the effect of including in the kit
one more of each part than the kit presently has. The
updated information is shown in table 2.This time, item B
has the highest priority, so one unit of it will be included
in the segment, and the probability of two or more demands
for B will replace the current demand probability in the

table. This procedure is continued until the segment is full.

TABLE 2

PARTS PRIORITIZATION - SECOND PASS

	mean anticipated demands	probability of an additional demand	size in cubic inches	priority
A	1	.264	20	.01320
B	3	.950	40	.02375
C	2	.865	50	.01730

IV. RESULTS

Weight vs Cube

As mentioned previously, the majority of pallet
positions in USAF airlift aircraft today have a weight
limitation of 10,354 pounds and dimensional restrictions of
88x108x96 or 912,384 cubic inches (24). This translates to
an allowable average density of 0.01135 pounds per cubic
inch if volume is used as the constraint. Density of the
165 parts in the WRSK kit was evaluated using the Statistix
statistical package. Mean density was 0.00729, standard
deviation was 0.00990 and the median value was 0.00508. The
lowest density was 0.00031 pounds per cubic inch and the
highest was 0.09257. A box and whisker plot for part
densities obtained from Statistix is displayed in figure 7.
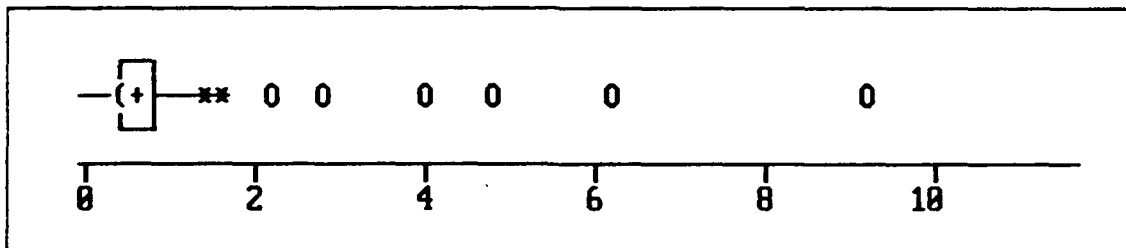
Figure 7. Box and Whisker Plot

In this plot, the '+' represents the mean, while
parentheses are used to indicate approximate 95% confidence
intervals. The asterisk is used to represent possible

outliers and 'O' represents probable outliers (25:9.18).
Outlier data points were verified to ensure their accuracy.

The discrepancy between median and mean, as well as the
large number of outliers called the normality of the data
into question. The Statistix package's Wilk-Shapiro/Rankits
Plots test was used to evaluate normality (25:8.4). The
output generated is shown in figure 8.
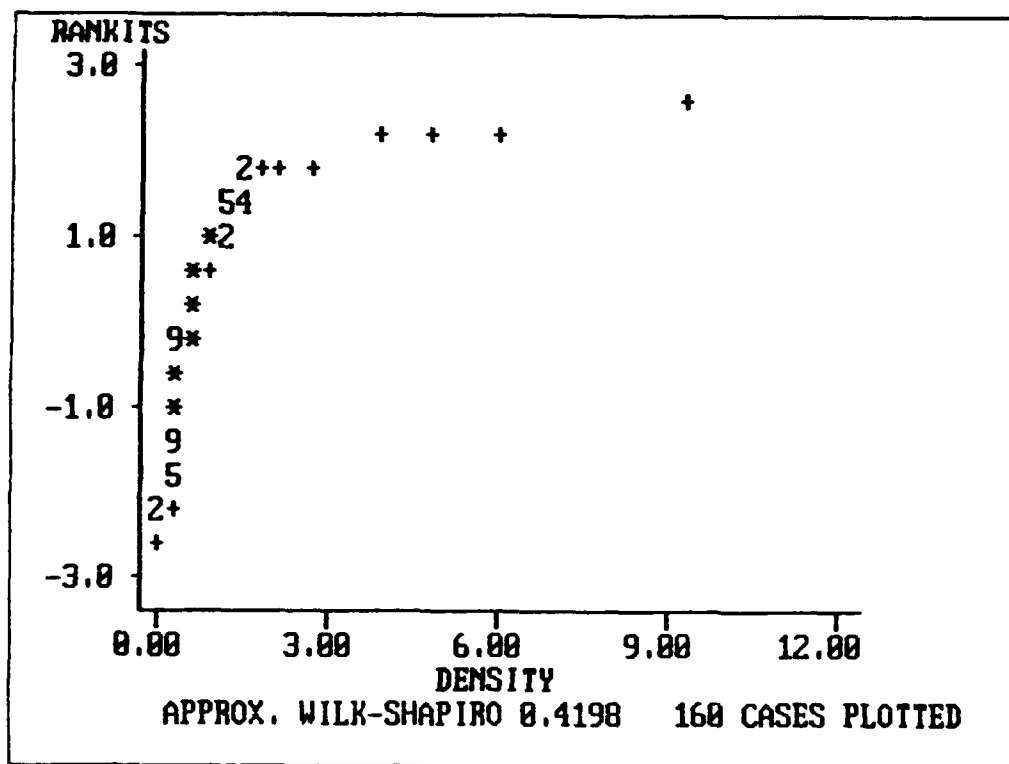
Figure 8. Wilk-Shapiro/Rankits Plot Output

In a Rankits plot, a straight line indicates normality.
The curvature evident in figure 8 makes normality highly
doubtful. Final confirmation is provided by the Wilk-
Shapiro value of 0.4198. The 160 cases plotted would
require a value of at least 0.9910 to be considered normal.

Since the maximum allowable density is within one standard deviation of the mean and the distribution is, in any case, decidedly not normal, no firm conclusion can be drawn statistically as to the dominance, in all cases, of volume over weight.

The skewness of the part densities indicates there is a small group of very dense parts. In fact, there are only 17 parts which exceed the allowable density, with the most dense weighing 0.09257 pounds per square inch.

Next, a hypothetical deployment was evaluated. The scenario selected was 12 aircraft for 10 days, flying a 2.0 utilization rate with an average sortie duration of two hours. The data obtained are displayed in table 3.

TABLE 3

PROJECTED PALLET DENSITIES

Pallet #	# of Parts	Weight	Volume	Density
1	343	6227	913331	.006818
2	174	5250	927416	.005661
3	207	5285	901055	.005865
4	194	5083	936768	.005426
5	203	5013	890655	.005628
6	193	5187	916716	.005658

None of these densities represent more than 60% of the maximum allowable density, so volume would appear to dominate.

Finally, all parts were ranked from most dense to least dense, and a pallet was constructed using the full authorized quantity of each successive part until the volume constraint was reached. This resulted in a total volume of 893,990 cubic inches and a weight of 9312.25 pounds, for a density of 0.0104165. This is less than the maximum allowable density of 0.01135, so for any subset of the current authorized F-16 WRSK, volume will represent a tighter constraint than weight.

Protection Per Pallet

The program was used to generate kits for hypothetical deployments of 6, 12, 18 and 24 aircraft. Each deployment was set up for 10 days duration, flying each aircraft twice a day with an average sortie duration of two hours. For each deployment, protection against stockout was evaluated for kits ranging from one to five pallets. The probability of no unfilled demands for the deployment is shown in table 4 and the number of parts per pallet is given in table 5.

The probabilities from table 4 are shown graphed in figure 9. The curves from left to right represent the 6, 12, 18 and 24 aircraft deployment packages respectively.

Note the 'S' shape of these curves. The work by the RAND Corporation, described in chapter two, might lead one to expect exponential curves similiar to the one in figure 5. The reason this shape was not obtained is what's being evaluated is the probability of no stockouts rather than the

TABLE 4

PROBABILITY OF NO UNFILLED DEMANDS

Pallets	6 Ship	12 Ship	18 Ship	24 Ship
0	0.00000	0.00000	0.00000	0.00000
1	0.23244	0.00170	0.00000	0.00000
2	0.94547	0.51835	0.12275	0.00749
3	0.99876	0.96234	0.80040	0.48107
4	0.99995	0.99845	0.98348	0.92046
5	0.99997	0.99995	0.99906	0.99297

TABLE 5

NUMBER OF PARTS PER PALLET

Pallets	6 Ship	12 Ship	18 Ship	24 Ship
1	305	341	374	401
2	196	174	171	163
3	181	206	180	177
4	202	193	182	180
5	209	202	191	199

number of stockouts expected to occur. Each of the first few parts added to the segment has a high probability of being needed and thus preventing a stockout. However, the probability of no stockouts is computed by multiplying the probability of no further demands for that item by the probability of no further demands for each of the other 164
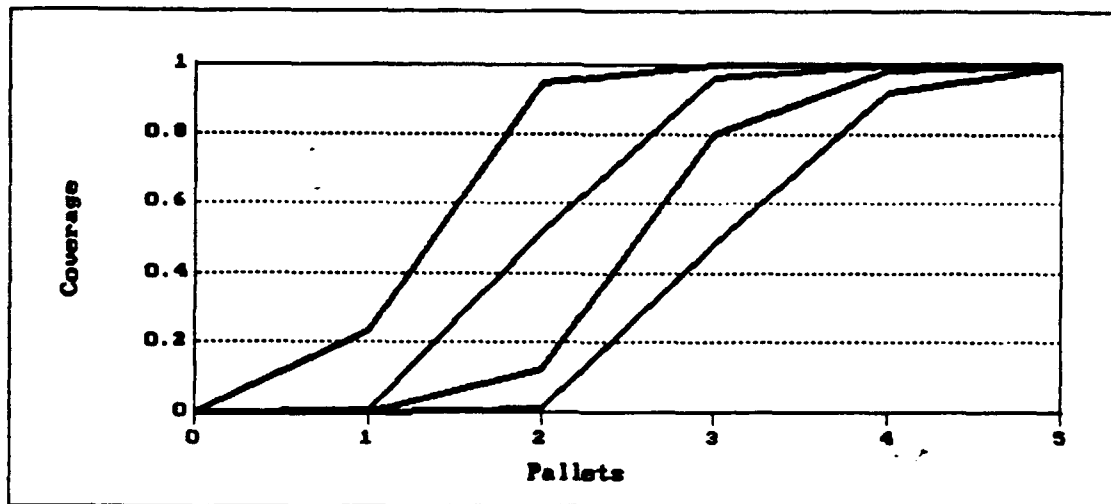
Figure 9. Probabilities Associated with Number of Pallets

parts. This means the probability of no stockouts for any
item is limited to a value no higher than the smallest
probability for any single item. Until some protection is
provided for all high demand items, the probability of no
additional requirements remains small.

A second significant finding is how quickly the
probability of no unfilled requirements converges on 100%.
For the six aircraft deployment, two pallets containing a
total of 501 parts provide a confidence level of .94547 and
for the 24 aircraft deployment, four pallets with 921 parts
provide a confidence level of .92046. It is important to
note here no allowance was made for wasted pallet space
resulting from packing inefficiency. It is possible,

especially if mobility storage bins are used, that packing
efficiency may be as low as 50%. In any case though, the
point is quickly reached, beyond which any increase in space
allocated to WRSK will result in a nearly insignificant
marginal improvement in protection against stockout.

It should be obvious one pallet of parts will provide
more protection from stockout for six aircraft at a given
level of flying activity than it will for 12 aircraft. What
may be less obvious is the optimal mix of parts for one
pallet in support of the smaller package is different than
the optimal mix of parts for one pallet in support of the
larger package. In other words, it is not possible to form
a single prioritized list and simply cut it off at different
places for different packages. The priority within the list
changes with any change in the projected level of flying
activity. This is because the mean of the probability
distribution for each part changes with the change in the
level of flying activity.

Summary

Component size is a significant, though frequently
overlooked consideration when segmenting WRSK kits.
Including size as a constraint and then selecting parts with
the best probability of use to size ratio will ensure
optimum use of the available airlift.

Due to the design of modern airlift aircraft and the
packaging techniques currently used on reparable aircraft
parts, volume takes precedence over weight as a constraint.

This was proven conclusively for the F-16 , and is likely to apply to other aircraft as well.

Use of the Poisson distribution provides a good estimation of short term demand requirements. However, the computational complexity involved in its implementation necessitates use of computer based algorithms.

The number of parts/pallets required to support a given deployment is not strictly proportional to the anticipated level of flying activity. A single pallet will not provide a reasonable level of protection for even the smallest deployment. However, after the first pallet, additional pallets provide a significant level of protection for all but the very largest deployments.

V. DISCUSSION

Limitations

It was initially hoped this research would result in a technique to accurately segment WRSK kits into pallet loads. This expectation was not met because of a lack of available information in the area of three dimensional bin packing efficiency. Studies of one and two dimensional algorithms are quite common in the literature, but even there, computational complexity is such that heuristic approaches are required. If dimensional information could be obtained for all boxes and bins that make up an existing kit, I believe general three dimensional pallet packing efficiency could be measured with sufficient accuracy to allow accurate segmentation into pallets. Lacking this information, this program could still be used to segment kits into pallets if the amount of wasted space can be estimated and this estimation fed into the program as space allocated to EOQ items.

Application

In spite of the shortcomings outlined above, the algorithm presented in this thesis study does represent an improvement in the method for selecting parts for inclusion in a WRSK segment. This improvement is based on its consideration of space as one of the constraints, and the result is a WRSK segment which optimizes use of all available space. Since most deployments are space

constrained, and since budget cuts will tend to further tighten those constraints, this algorithm should enable managers to make better decisions. The prioritized list, which it generates for a specified deployment, can be used to select items to fill whatever space is allocated to WRSK.

A caution is in order here, since the algorithm tends to select smaller items first. Items will probably have to be packed on the first pallet in reverse order of their selection, to put the larger items on the bottom. This will require some trial and error since the cutoff points for pallets are not accurate. This should only be necessary for the first pallet, since beyond that point, sizes of the selected parts are more evenly distributed.

Applicability to Other Weapon Systems

Although the F-16 was used as the focus of this study, none of the algorithms employed are in any way unique to this weapon system. Assuming the appropriate databases are obtained, this procedure should apply to any weapon system. However, the program in appendix two does not take into account indenture relationships between parts, that is, each part in the kit is assumed to repair a unique malfunction. If some of the parts in the kit are shop replaceable components of line replaceable units which are also in the kit, quantities for these items will be overstated. It is possible, though not likely, that weight may become a dominant constraint for some weapons systems. However, as

previously pointed out, this would simplify the algorithm rather than complicating or negating it.

Risk of Loss

This algorithm is effective in placing the most needed items on the first airlift aircraft. However, it also increases the vulnerability of the squadron to the loss or delay of that aircraft. This is probably an acceptable risk during peace time, but during war, not only is the probability of loss increased, but so is the cost of loss in terms of military capability. Because of the possibility of loss or delay of any one pallet in the event of hostilities, it may not be prudent to pack all of the most needed items on one pallet, or even one airplane. A possible solution would be to combine the first two pallet loads and then split them as evenly as possible by quantity per line item back into two pallets. These two pallets could then be loaded on different aircraft, preferably the first two with pallet spaces allocated to WRSK.

Recommendations for Further Research

1. There is a need for research into the efficiency of three dimensional bin packing. This would permit much more accurate assignment of parts to specific pallets. As previously mentioned, actual three dimensional bin packing algorithms would be extremely difficult to derive. However, they are not really required. For the limited number of pallets required by most organizations, individual judgement

as to placement of items on pallets is sufficient. What is needed, is an estimation of the efficiency of space utilization with such methods. This could be done by simply stacking parts on pallets until the allowable height is reached and then comparing the total of the individual parts' volumes to the length times width times height measurements of the completed pallet.

2. Research is required into the effects of climate and geography on consumption. Hydraulic systems are generally hypothesized to fail more frequently in cold weather and electronic systems in hot weather. Also there appears to be considerable variation in consumption of such things as tires from one geographic area to the next. Although the literature agrees on the concept of these factors having an impact, no one has quantified this impact. This could be done by comparing similiar aircraft stationed at different bases, or by comparing consumption rates of a single unit, both at home and deployed.

3. A valuable extension of this work would permit tailoring of the WRSK listing before computation is begun. This tailoring could delete items which are deemed nonessential for the anticipated deployment and shop replaceable units for which the associated shop equipment is not being deployed. This would increase the probability of a successful deployment without the normally attendant increase in airlift requirements.

Conclusion

This thesis study represents the first step toward an improved method of segmenting war readiness spares kits. The associated program, listed in appendix B, can be used to generate prioritized listings of parts for deployments of various sizes and durations. As it is used, statistics should be kept on packing efficiency with a goal of obtaining a mean efficiency which could be used to make pallet requirements identification more accurate. Alternatively, research could be specifically directed to this area. Pallets could be built using reparable item containers and lists generated by this program.

Further development and implementation of the ideas presented in this thesis will increase our combat capability and reduce the support costs for deployed forces.

APPENDIX A: War Readiness Spares Kit Listing

NSN	Noun	Wt	Len	Wid	Ht	Dmd Rate
1005000566753	GUN M61A1	236.00	21	21	35	0.00013
1005007755578	ADAPTER,RECOIL	13.00	11	6	5	0.00037
1005010086283	DISPOSAL	40.00	5	15	15	0.00013
1005010418667	HYD DRIVE	21.00	17	17	13	0.00037
1005010446174	DRUM UNIT,AMMO	244.00	36	30	35	0.00169
1005010463536	TRANSFR UNIT,AMMO	46.00	21	21	17	0.00610
1005010502735	EXIT UNIT,AMMO	14.00	17	17	17	0.00403
1005010502736	ENTRANCE,AMMO	13.00	17	13	9	0.00322
1005010556484	ACESS UNIT,LOADING	20.00	21	17	17	0.00322
1260011938861	MULTIF DIS	29.00	25	15	15	0.00160
1260012511150	PD GENERATOR	28.00	25	15	15	0.00257
1270012319800	PROG-SIG-PR	162.00	25	10	7	0.00712
1270012330011	MLPRF RECEIVER	176.00	39	20	25	0.00525
1270012352370	EFCC FIRE CONTROL	53.75	31	17	15	0.00485
1270012383662	DUL MOD TRANSMITR	129.00	25	19	17	0.00570
1270997207741	SIGHT,HEAD UP	19.25	25	15	15	0.00001
1270997714187	DSPLY UNIT,HEAD UP	50.00	39	17	21	0.00392
1280011091499	MISSLE UNIT ASSY	14.00	27	10	9	0.00063
1280011963702	DTU PWR CONVERTER	11.50	15	15	17	0.00092
1560011026385	FUEL TANK, EPU	98.00	58	22	23	0.00037
1560011358956	BOX ASSY,LEADING ED	99.00	97	12	20	0.00013
1620010492910	INPUT POTENTIOMETER	3.00	6	6	11	0.00013
1620010710535	AXLE LH-M	20.00	14	14	14	0.00013
1620010710537	AXLE RH-M	20.00	14	14	14	0.00013
1620011627518	SHOCK STRUT ASSY	121.00	38	27	18	0.00013
1620011951141	STRUT MLG	63.00	44	12	12	0.00006
1630008521432	WHEEL NOSE	13.00	12	12	9	0.00322
1630010389239	WHEEL MAIN	41.50	18	18	9	0.00412
1630011996430	BRAKE	51.25	16	16	9	0.00201
1650010568914	PUMP HYD EPU	16.50	13	13	19	0.00013
1650011061594	ISA RUDDER	53.00	38	18	15	0.00037
1650011589392	ACTUATOR,ELECTRO-ME	13.75	15	15	15	0.00040
1650011657203	ISA FLAP ACTUATOR	87.00	40	21	16	0.00050
1650012289276	CONST SPEED DRIVE	135.00	24	24	24	0.00059
1660001952729	O2 REGULATOR	5.00	11	11	11	0.00169
1660005678852	LOX CONVERTER	23.00	19	17	15	0.00246
1660010525354	SENSOR CONTROLLER,A	3.00	15	9	9	0.00034
1660011559146	TURBINE	17.00	15	15	13	0.00053
1660011965999	CONTROLLER SENSOR	3.00	10	7	4	0.00056
1660012176555	VALVE 324806-1-1	11.00	21	15	10	0.00047
1680012301279	ACTUATOR ELCT/MGNTC	19.00	17	13	9	0.00009
1680012585608	EPU CONTRL, SPEED	11.50	13	13	19	0.00013
1680012768711	ACTUATOR ELCT/MGNTC	19.00	17	13	9	0.00009
2835010738989	GENERATOR	1.75	8	8	13	0.00013
2835011156111	SHAFT TURBINE PTO	16.00	33	13	15	0.00209
2835011160006	POWER UNIT EPU	71.50	37	27	19	0.00013
2835011543533	JET FUEL STARTER	75.00	29	19	19	0.00037
2835012080169	AD GEAR BOX	225.00	53	28	31	0.00021

NSN	Noun	Wt	Len	Wid	Ht	Dmd Rate
2840011028596	OIL TANK ASSEMBLY	17.50	33	22	12	0.00073
2840011802935	LINER,AUGMENTOR NOZ	1.50	13	8	3	0.00052
2840011802941	LINER ASSEMBLY,AUGM	3.00	13	14	3	0.00053
2910011355681	FUEL CONTROL,START	12.25	15	15	17	0.00013
2915009306611	ACTUATOR 40283	1.75	9	6	4	0.00021
2915010414481	PROPORT FU	18.25	25	19	17	0.00037
2915011332467	F16 BUC	32.50	25	19	17	0.00110
2915011807299	GEAR PUMP	43.75	21	15	15	0.00009
2915012039538	F16 EEC X	30.00	36	26	24	0.00113
2925011150306	CNTRL JFS	6.50	11	11	17	0.00037
2935012377995	HEAT EXCH	26.00	25	19	17	0.00015
4320006396172	PUMP ASSY	9.00	17	13	15	0.00086
4810010546013	VALVE HALDON	4.50	11	11	13	0.00403
4810011237254	VALVE, P&V	8.75	15	15	17	0.00047
4810011307379	VALVE	11.00	15	15	17	0.00044
4810012590464	VALVE, JFS	1.50	7	7	5	0.00013
5810000613386	KIT 1A	14.00	10	8	13	0.00001
5821010621019	RT1300 REC	14.00	15	15	17	0.00155
5821012287057	RECEIVER/TRANS	20.00	26	15	15	0.00259
5826010121938	RT1159A RT	35.00	25	15	14	0.00130
5826010409798	ILS R71BA0	14.00	12	6	4	0.00055
5831005358123	INTERCOM	10.00	11	11	13	0.00013
5841012301284	CONVERTER,SGNL DATA	10.00	11	11	13	0.00050
5841012469183	RECVR/TRNSMTR RADAR	22.00	6	6	10	0.00200
5865000076945	OSCILLATOR 578R532	3.00	9	6	4	0.00098
5865000076949	OSCILLATOR 578R535	6.00	13	13	15	0.00309
5865000076950	DRIVE CON Q119	2.00	9	6	3	0.00073
5865000094381	T W TUBE Q119	13.00	27	10	9	0.00086
5865001559243	2BOARD AYL Q119	1.00	9	6	4	0.00030
5865001559262	DRIVE CONTROL	2.00	9	6	3	0.00043
5865001559264	CONT DRIVE	2.00	9	6	4	0.00081
5865001559266	T W TUBE Q119	14.00	27	10	9	0.00180
5865001559489	BOARD ASSY Q119	1.00	13	8	3	0.00116
5865001955987	OSCILLATOR BOARD	1.00	9	6	4	0.00068
5865001994195	CONTROL ASSY	13.00	21	15	9	0.00124
5865003073292	CKT CRD ASSY Q119	1.00	8	8	3	0.00236
5865003151482	AMPLIFIER ASSY Q119	1.00	6	5	4	0.00167
5865003217636	CKT CRD ASSY	1.00	9	6	3	0.00094
5865003655459	DUAL VIDEO Q119	2.00	8	6	6	0.00210
58650.3713344	OSCILLATOR 578R534	4.00	9	9	13	0.00404
5865004520326	P C BD AYQ119	2.00	9	6	5	0.00025
5865005562035	BD ASSY ALQ119	1.00	8	7	5	0.00064
5865005562036	BD ASSY ALQ119	2.00	9	8	1	0.00086
5865005562039	BD ASSY ALQ119	1.00	9	6	5	0.00163
5865005562055	BD ASSY ALQ119	1.00	9	6	3	0.00090
5865005562103	CKT CD ASY	.75	9	6	3	0.00081
5865005562104	BD ASSY ALQ119	1.00	8	6	5	0.00077
5865005562122	BD ASSY ALQ119	1.00	9	6	3	0.00081
5865005562124	COMBINER	.50	5	3	2	0.00077
5865005562141	INPUT AMP ASSY	.75	6	5	4	0.00047
5865010156248	ELECT COMP	1.00	9	6	3	0.00068
5865010211647	PROGRAMMER	10.00	15	15	17	0.00048

NSN	Noun	Wt	Len	Wid	Ht	Dmd Rate
5865010450982	DISPENSING SET,COUN	16.00	25	15	15	0.00126
5865010481589	CONTROL,INDICATOR	10.00	21	15	9	0.00425
5865010491178	TDU AUX 69	1.00	9	6	3	0.00040
5865010535396	TLC ALR69	1.00	13	8	4	0.00017
5865010805675	REC COUNTERMEASURES	16.00	21	15	9	0.00127
5865010920386	SEQUENTIAL SW ASSY	9.00	13	13	15	0.00102
5865011074586	IP1310 IND	13.00	12	12	18	0.00067
5865011106043	REC ALR69	18.00	25	14	14	0.00069
5865011133354	BD QRC80+1	.75	9	6	3	0.00169
5865011163884	AMP,RF QRC8Q+1	.50	6	5	3	0.00038
5865011202041	CKT CRD QRC80+1	.50	7	6	3	0.00090
5865011213832	CKT CRD QRC80+1	2.00	9	6	3	0.00116
5865011244985	CKT CRD QRC8Q+1	.75	9	6	3	0.00090
5865011311336	CKT CRD QRC8001	1.00	6	5	3	0.00043
5865011526690	CKT CRD 8001	1.00	9	6	3	0.00141
5865011527409	CKT CRD 8001	1.00	9	6	3	0.00202
5865011527410	ENCODER BD	1.00	9	6	3	0.00060
5865011549042	AMP/RADIO Q119	11.00	27	10	9	0.00008
5865011549125	AMP DETECT	4.00	13	8	4	0.00134
5865011631669	SIGNAL PROCES	12.00	20	14	9	0.00302
5865011678780	MLS GEN CARD	.75	9	6	3	0.00077
5865011692201	RF MODULE*	15.00	21	15	9	0.00296
5865011795600	TRIPLEXER	2.00	9	6	4	0.00090
5865012490130	REC,COUNTERMEASURES	25.00	21	15	9	0.00183
5895011126380	IFFF/RT	25.00	26	15	15	0.00291
5895012301075	DATA ENTRY	42.00	24	20	14	0.00189
5915010558592	FILTER,CHAFF&FLARE	4.00	10	10	12	0.00062
5945011709363	ACRIU INTERFACE	9.00	20	9	7	0.00060
5985011469283	ANTENNA	7.10	15	15	17	0.00054
5985012122950	RADAR ANTENNA,RE	70.00	26	26	26	0.00153
5999000037506	CKT CD ASY	.75	7	5	3	0.00038
5999010135206	BOARD AY119	1.00	9	6	3	0.00068
5999010803978	JRIU	9.75	27	10	9	0.00044
6110011656844	10 KVA GEN CONTROL	5.00	21	15	15	0.00061
6110011850452	60 KVA GEN	6.00	13	13	15	0.00064
6115012368434	60 KVA GEN/ALT	6.00	15	15	17	0.00030
6115012465622	GEN 10KVA	50.00	25	15	15	0.00088
6130000037464	POWER SUPPLY S119	10.00	21	15	10	0.00124
6130010517518	CHARGER,BATTERY	11.00	13	13	19	0.00147
6130010770497	HGHVLT PWR SUP Q119	6.00	11	11	11	0.00253
6130011498915	POWER SUPPLY	5.00	13	9	4	0.00061
6130012072734	PWR SP DIS	3.00	11	11	11	0.00035
6130012099062	CONV REG	7.00	13	9	4	0.00050
6130012486604	PWR SUPPLY,ENT MST	11.00	8	8	24	0.00067
6130012577165	LOW VLT PWR SUPPLY	10.00	16	9	16	0.00318
6340001739074	ICE DETECTOR	12.00	12	12	12	0.00042
6605012562380	INU,LN39	90.00	36	31	30	0.00385
6610002008832	INDICATOR,ATTITUDE	8.00	13	13	22	0.00066
6610010891018	COMPUTR CADC	12.75	25	15	15	0.00234
6610010929846	ADI	10.00	13	13	19	0.00088
6610011150131	ALTIMETER	10.00	13	13	19	0.00112
6610011190832	INDICATOR	9.00	13	13	24	0.00181

NSN	Noun	Wt	Len	Wid	Ht	Dmd Rate
6610011480712	ELEC COMP	39.50	25	19	17	0.00210
6610012226439	XMTR AOA	1.00	13	13	19	0.00079
6615007076478	GYRO RATE	2.00	8	8	11	0.00063
6615011273160	FCP 14ADO	15.50	15	15	17	0.00121
6615011297445	TRM PNL AS	5.75	15	15	17	0.00067
6615012203851	FLIGHT COMPUTER	63.75	34	20	17	0.00213
6620011670874	TRANSMITTR,POSITION	39.00	27	10	10	0.00058
6620011805183	INDICATOR,TEMP	3.50	8	8	11	0.00055
6680009763923	INDICATOR,DIG.	3.75	6	6	11	0.00074
6680010749369	TRANS,FUEL FLOW	6.25	11	11	13	0.00073
6680011288000	RECORDER,ENGINE	6.75	11	11	11	0.00135
6685004504489	XMITTER,HYD	2.75	6	6	11	0.00028

```
*                   THE DEPLOYMENT PLANNER
*
*                   Main Menu Module
*
*               Author:  Larry Martinsen
*
*     This is the driver program for the deployment planning
system
*
*    Programs called:   CREATE
*                       MODIFY
*                       DELETE

SET SAFETY OFF
SET TALK OFF
SET BELL OFF
SET STATUS OFF
SET SCOREBOARD OFF

PUBLIC
mnewdep,mnumac,masd,mnumdays,muterate,drecno,totvolume,;
        totwt,parts,volume

option = 0
DO WHILE option = 0

*    Draw Opening Menu

  SET COLOR TO W+/B      &&  Standard Blue Background
  CLEAR
  @7,20 SAY 'WELCOME TO THE DEPLOYMENT PLANNER'
  @11,20 SAY 'OPTIONS:'
  @13,22 SAY '1. Review Existing Deployment Kit'
  @14,22 SAY '2. Create New Deployment Kit'
  @15,22 SAY '3. Delete Existing Deployment Kit'
  @16,22 SAY '4. Quit'
  @18,20 SAY 'Select Number of Choice  'GET option PICTURE '9'

*    Force Valid Input

  DO WHILE option < 1 .OR. option > 4
    READ
  ENDDO

*    User Has Elected to Modify An Existing Deployment

  IF option = 1 THEN
    DO MODIFY
    option = 0
```

```
      ENDIF

*     User Selected 'Create',Get Deployment Name

   IF option = 2 THEN
     newdep = '                        '
     @20,10 SAY 'What is the name of this deployment?'
     @20,48 GET newdep PICTURE 'AXXXXXXXXXXXXXXXXX'
     READ

*     Make Sure Specified Name Is Unique

     duplicate = "F"
     USE DEPLOYMENTS
     GO TOP
     DO WHILE .NOT. EOF()
       IF DEPNAME = newdep
         duplicate = "T"
         drecno = RECNO()
       ENDIF
       SKIP
     ENDDO
     CLOSE ALL

*     If duplicate exists, notify user and try again

     IF duplicate = "T"
       @22,10 SAY 'A deployment of that name already exists'
       option = 0
*     Otherwise present deployment input screen

     ELSE
       DO CREATE
       option = 0
     ENDIF
   ENDIF

*     User selected 'Delete'

   IF option = 3 THEN
     DO DELETE
     option = 0
   ENDIF

*     User Selected 'Quit', Terminate Program

   IF option = 4 THEN
     USE SEGMENT
     ZAP
     CLOSE ALL
     CLEAR ALL
     option = 5
   ENDIF
ENDDO
```

```
*                       Create Module
*
*    Called by WRSKIN when the user selects 'Create'
*    This Program calls COMPUTE

*    User Selected 'Create',Get Deployment Name

     USE DEPLOYMENTS

*    Set up the input screen for the scenario

     option = 0
     STORE 0 TO meoql,meoqw,meoqh
     CLEAR
     @3,10 SAY 'CREATE NEW DEPLOYMENT KIT'
     @5,15 SAY newdep
     @8,10 SAY 'Number of Aircraft to be Supported'
     @10,10 SAY 'Number of Days Support Required'
     @12,10 SAY 'Anticipated Aircraft Utilization Rate'
     @14,10 SAY 'Anticipated Average Sortie Duration'
     @16,10 SAY 'Number of Pallet Positions Available'
     @18,10 SAY 'How Much Space Do You Want To Reserve For '
     @19,10 SAY 'EOQ Items (in inches)?'
     @21,10 SAY 'Length:        Width:         Height:'

*    lnitialize input variables

     STORE 0 TO mnumac,mnumdays,muterate,masd,mpallets
     STORE 'N' TO noness

*    Obtain values

     @8,46 GET mnumac PICTURE '99'
     @10,43 GET mnumdays PICTURE '99'
     @12,49 GET muterate PICTURE '9.9'
     @14,50 GET masd PICTURE '9.9'
     @16,48 GET mpallets PICTURE '99'
     @21,20 GET meoql PICTURE '99'
     @21,35 GET meoqw PICTURE '99'
     @21,52 GET meoqh PICTURE '99'
     READ

*    Compute total volume in inches of space dedicated to WRSK

     eoqtot = meoql*meoqw*meoqh
     totvolume = mpallets*912384-eoqtot

*    Save the new scenario

     APPEND BLANK
```

```
REPLACE DEPNAME WITH newdep,;
        NUMAC WITH mnumac,;
        NUMDAYS WITH mnumdays,;
        UTERATE WITH muterate
REPLACE ASD WITH masd,;
        PALLETS WITH mpallets,;
        EOQL WITH meoql,;
        EOQW WITH meoqw,;
        EOQH WITH meoqh
DO COMPUTE
RETURN
```

```
*                       Modify Module
*
*     Called by WRSKIN when user elects to modify an
*     existing deployment

*     Calls COMPUTE


  USE DEPLOYMENTS

*     List the deployment scenarios from the file

  num = 0
  column = 2
  line = 11
  GO TOP
  CLEAR
  @7,15 SAY 'SELECT YOUR DEPLOYMENT'
  @9,11 SAY '0. Return to main menu'
  DO WHILE .NOT. EOF()
    @line,column SAY RECNO()
    @line,(column+10) SAY '.'
    @line,(column+12) SAY DEPNAME
    STORE line+1 TO line
    STORE num+1 TO num
    SKIP
    IF line > 20 THEN
      column = column+20
      line = 11           .
    ENDIF
  ENDDO

*     Let the user select which scenario he wants

  drecno = 10
  @22,15 SAY 'Select Number of Choice  'GET drecno PICTURE '9'
  DO WHILE drecno > num
    READ
  ENDDO
  IF drecno = 0 THEN
    RETURN
  ENDIF

*     Read the scenario in from disk

 GOTO drecno
  mnumac = NUMAC
  mnumdays = NUMDAYS
  muterate = UTERATE
  masd = ASD
  mpallets = PALLETS
  meoql = EOQL
```

```
   meoqw = EOQW
   meoqh = EOQH
   CLEAR

*    Display the scenario on the screen

   @3,10 SAY 'REVIEW OF DEPLOYMENT KIT FOR'
   @5,15 SAY DEPNAME
   @8,10 SAY 'Number of Aircraft to be Supported'·
   @8,46 SAY NUMAC
   @10,10 SAY 'Number of Days Support Required'
   @10,43 SAY NUMDAYS
   @12,10 SAY 'Anticipated Aircraft Utilization Rate'
   @12,49 SAY UTERATE
   @14,10 SAY 'Anticipated Average Sortie Duration'
   @14,47 SAY ASD
   @16,10 SAY 'Number of Available Pallet positions'
   @16,48 SAY PALLETS
   @8,46 GET mnumac PICTURE '99'
   @10,43 GET mnumdays PICTURE '99'
   @12,49 GET muterate PICTURE '9.9'
   @14,47 GET masd PICTURE '9.9'
   @16,48 GET mpallets PICTURE '99'
   @18,10 SAY 'Amount of Space Reserved For EOQ WRSK (in inch-
es)'
   @20,10 SAY 'Length:        Width:        Height:'
   @20,20 SAY EOQL
   @20,35 SAY EOQW
   @20,52 SAY EOQH
   @20,20 GET meoql PICTURE '99'
   @20,35 GET meoqw PICTURE '99'
   @20,52 GET meoqh PICTURE '99'
   @22,10 SAY 'Modify if Desired or Press Return to Continue'

*    Obtain user changes

   READ
   eoqtot = meoql*meoqw*meoqh            && Compute volume for
EOQ
   totvolume = mpallets*912384-eoqtot    && Compute total
volume

*    Save the changes

   REPLACE NUMAC WITH mnumac,;
          NUMDAYS WITH mnumdays,;
        •  UTERATE WITH muterate,;
          ASD WITH masd,;
          PALLETS WITH mpallets,;
          EOQL WITH meoql,;
          EOQW WITH meoqw,;
          EOQH WITH meoqh
   DO COMPUTE                    && Run the computation module
   RETURN
```

```
*                      Delete Module
*
*      Called by WRSKIN
*      Chains back to WRSKIN when done

*   user has elected to delete a record

CLOSE ALL
USE DEPLOYMENTS
CLEAR
@7,10 SAY 'Which deployment do you want to delete?'
@9,9 SAY "0.   Don't delete anything.   Return  to  previous
menu."

*      List all stored scenarios

num = 0
column = 2
line = 11

DO WHILE .NOT. EOF()
  @line,column SAY RECNO()
  @line,(column+10) SAY '.'
  @line,(column+12) SAY DEPNAME
  line = line+1
  num = num+1
  SKIP
  IF line>20 THEN              &&  Form a second column if needed
    column = column+20
    line = 11
  ENDIF
ENDDO

*      Obtain user input

drecno = -1
@22,15 SAY 'Select number of choice:   'GET drecno PICTURE '9'

*      Check for out of range values

DO WHILE drecno>num .OR. drecno<0
  READ
ENDDO

*      Delete the indicated record

IF drecno>0 THEN
  GOTO drecno
  DELETE
  PACK
ENDIF
RETURN      &&      Go back to WRSKIN
```

```
*          This segment establishes the initial priority for
*          all parts in the WRSK kit
*
*     Called by MODIFY and CREATE


CLEAR
@7,15 SAY 'COMPUTATION IS IN PROGRESS'
@9,10 SAY 'Please Wait For The Report Options Menu'
@12,17 SAY 'Scanning The WRSK File'

SELECT 1
USE SEGMENT  && to store selected parts
SELECT 2
USE WRSK      && initial parts listing
volume = 0   && used to accumulate segment volume
totwt = 0    && used to accumulate segment weight
n = 0        && stores mean demands
GOTO TOP


*     Initialize WRSK priorities

DO WHILE .NOT. EOF()
   lambda  =  DDR*mnumac*masd*mnumdays*muterate     && compute
lambda - mean demands
   probn = 1-(lambda^n*EXP(-lambda))                && prob of n or
more demands
   mpriority = (probn*1000000)/(LEN*WID*HT)     && kit inclusion
priority
   REPLACE PRIORITY WITH mpriority,;
           QIS WITH 0,;
           PROB WITH probn

   SKIP
ENDDO
INDEX ON PRIORITY TO PRIORITY

&&        When parts have been indexed in priority order, the
&&        first part in the list will be the best selection
&&        and first inclusion in the segment

GOTO BOTTOM
mnsn = NSN
mwuc = WUC
mnoun = NOUN
mlen = LEN
mwid = WID
mht = HT
mqau = QAU
mqoh = QOH
mddr = DDR
mqis = QIS
```

```
*      Recompute priority for part selected

n = QIS+1
lambda = DDR*mnumac*masd*mnumdays*muterate
probn = PROB-(lambda^n*EXP(-lambda))
mpriority = (probn*1000000)/(LEN*WID*HT)
REPLACE PRIORITY WITH mpriority,;
        QIS WITH 1,;
        PROB WITH probn

totwt = WT/100

*      Put the part in the segment

SELECT 1
APPEND BLANK
REPLACE NSN WITH mnsn,;
        WUC WITH mwuc,;
        NOUN WITH mnoun,;
        LEN WITH mlen,;
        WID WITH mwid
REPLACE HT WITH mht,;
        QAU WITH mqau,;
        QOH WITH mqoh,;
        DDR WITH mddr,;
        QIS WITH mqis

volume = volume+LEN*WID*HT          && accumulate total segment
volume

&&      Continue the procedure until  the segment is full

parts = 1

*      Continue until the segment is full

DO WHILE volume < totvolume
  @12,17 SAY parts PICTURE '999'
  @12,20 SAY ' Parts Selected                '
  SELECT 2
  GOTO BOTTOM
  n = QIS+1
  i = n
  nfac = 1
  DO WHILE i>1
    nfac = nfac*i
    i = i-1
  ENDDO
  lambda = DDR*mnumac*masd*mnumdays*muterate
  probn = PROB-(lambda^n*EXP(-lambda))/nfac
  mpriority = (probn*1000000)/(LEN*WID*HT)
  REPLACE PRIORITY WITH mpriority,;
          QIS WITH QIS+1,;
          PROB WITH probn
```

```
      GOTO BOTTOM
      mnsn = NSN
      mwuc = WUC
      mnoun = NOUN
      mlen = LEN
      mwid = WID
      mht = HT
      mqau = QAU
      mqoh = QOH
      mddr = DDR
      mqis = QIS

      totwt = totwt+(WT/100)

      SELECT 1
      APPEND BLANK
      REPLACE NSN WITH mnsn,;
              WUC WITH mwuc,;
              NOUN WITH mnoun,;
              LEN WITH mlen,;
              WID WITH mwid
      REPLACE HT WITH mht,;
              QAU WITH mqau,;
              QOH WITH mqoh,;
              DDR WITH mddr,;
              QIS WITH mqis
     volume = volume+LEN*WID*HT
     parts = parts+1
ENDDO
CLOSE ALL
DO WRSKOUT    &&  go to the report options menu
```

```
*      WRSKOUT

*      This segment provides the user with options for output
*
*      Called by MODIFY and CREATE
*      Chains back to WRSKIN when done

*      Determine format for output

option = 0
DO WHILE option <> 5
  CLEAR
  @7,10 SAY 'COMPUTATION IS COMPLETE'
  @11,10 SAY 'OPTIONS:'
  @13,12 SAY '1.  Summary'
  @14,12 SAY '2.  Stock Number Listing'
  @15,12 SAY '3.  Priority Listing'
  @16,12 SAY '4.  Return to Opening Menu'
  @17,12 SAY '5.  Quit'
  @19,10 SAY 'Select Number of Choice' GET option PICTURE '9'

*      Error checking

  DO WHILE option < 1 .OR. option > 5
    READ
  ENDDO

  IF option < 4 THEN
    pstoggle = ' '
    @22,10 SAY 'Output to (P)rinter or (S)creen?' GET pstoggle
PICTURE '!'
    DO WHILE pstoggle <> 'P' .AND. pstoggle <> 'S'
      READ
    ENDDO
    IF pstoggle = 'P' THEN
      SET DEVICE TO PRINT
    ELSE
      SET DEVICE TO SCREEN
    ENDIF
  ENDIF

*      Summary report requested

  npallets = (volume/912384)+1
  IF option = 1 THEN
    USE DEPLOYMENTS
    GOTO drecno
    CLEAR
    @3,10 SAY 'SUMMARY OF DEPLOYMENT FOR '
    @5,20 SAY DEPNAME
    @8,10 SAY 'Number of Aircraft:'
    @8,30 SAY NUMAC
    @10,10 SAY 'Number of Days of Flying:'
```

```
      @10,37 SAY NUMDAYS
      @12,10 SAY 'Utilization Rate:'
      @12,29 SAY UTERATE
      @14,10 SAY 'Average Sortie Duration:'
      @14,36 SAY ASD
      @16,10 SAY 'Number of Pallet Positions:'
      @16,39 SAY npallets PICTURE '99'
      @18,10 SAY 'Number of Parts Selected:'
      @18,37 SAY parts
      @20,10 SAY 'The Probability of No Unmet Requirements is:'
   @22,10 say totwt
   @22,20 say volume

 *     Determine probability of a successful trip

      cumprob = 1
      USE WRSK
      GOTO TOP
      DO WHILE .NOT. EOF()
        n = QIS+1
        i = n
        nfac = 1
        DO WHILE i > 1
          nfac = nfac*i
          i = i-1
        ENDDO
        cumprob = cumprob*(1-PROB)
        IF pstoggle = 'S' THEN
          @20,56 SAY cumprob PICTURE '9.99999'
        ENDIF
        SKIP
      ENDDO
      @20,56 SAY cumprob PICTURE '9.99999'
      @ 22,1 say ''
      WAIT                  && Pause while user reads screen

      option = 0
    ENDIF


    IF option = 2 THEN   && Print output in stock number order
      USE WRSK
      IF pstoggle = 'p' THEN
        REPORT FORM SORD
      ELSE
        CLEAR
        @2,5 SAY 'NSN                      Noun                   WUC
QAU    QOH    QIS'
        line = 4
        DO WHILE .NOT. EOF()
          @line,5 SAY NSN
          @line,25 SAY NOUN
          @line,45 SAY WUC
          @line,52 SAY QAU
```

```
                    @line,60 SAY QOH
                    @line,68 SAY QIS
                    line = line+1
                    IF line = 24 THEN
                      line = 4
                        WAIT
                    ENDIF
                    SKIP
                  ENDDO
                  @line,0 CLEAR
                  WAIT
              ENDIF
              option = 0
          ENDIF

          IF option = 3 THEN           && Print output in priority order
              USE SEGMENT
              IF pstoggle = 'p' THEN
                REPORT FORM PORD
              ELSE
                CLEAR
                @2,5 SAY 'NSN                    Noun                    WUC
QAU      QOH      QIS'
                line = 4
                DO WHILE .NOT. EOF()
                  @line,5 SAY NSN
                  @line,25 SAY NOUN
                  @line,45 SAY WUC
                  @line,52 SAY QAU
                  @line,60 SAY QOH
                  @line,68 SAY QIS
                  line = line+1
                  IF line = 24 THEN
                    line = 4
                      WAIT
                  ENDIF
                  SKIP
                ENDDO
                @line,0 CLEAR
                WAIT
              ENDIF
              option = 0
          ENDIF
          .
          IF option = 4 THEN           && Return to the opening menu
              option = 0
              RETURN
          ENDIF

      ENDDO
      CLOSE ALL                        && Terminate the program
```

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VITA

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REPORT DOCUMENTATION PAGE

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13. ABSTRACT (Maximum 200 words)

This study examines the segmentation of war readiness spares kits. Specifically, it looks at the possibility of using the volume of available airlift as an additional constraint in the segmentation algorithm. The system currently in use by the Air Force considers only the probability of an item being required.

This paper specifies an algorithm which establishes a quantity of each item for inclusion in the segment. This quantity is directly proportional to the probability of use and inversely proportional to the volume of airlift space which it will require. The probability distribution used is Poisson with a mean based on historical failures per flying hour. The algorithm is implemented in a dBase III+ program which provides a prioritized listing of parts for inclusion in the kit segment.

The algorithm investigated does not consider indenture relationships or the relative usefulness of the various parts. Only reparable parts were considered. The final section of this study provides recommendations for additional research which could further refine this model.

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